# *ESO observing programme 106.20Z8*
# *PENELLOPE: the ESO data legacy program to complete the Hubble UV Legacy Library of Young Stars (ULLYSES)*

## Abstract

The PENELLOPE Large Programme (Pr.Id. 106.20Z8) is a multi-instrument spectroscopic survey aimed at obtaining complementary data to the targets of the ULLYSES program. The latter is a *Hubble* Space Telescope (HST) Director's Discretionary Time that was executed in a three-year period, from HST Cycle 27 through Cycle 29 (2020-2022). About 500 orbits of the ULLYSES program are being devoted to the study of about 70 young low-mass stars in various star-forming regions in the Southern Hemisphere. The HST ULLYSES program is aimed at obtaining low- and medium-resolution spectra of young stars covering the wavelength range from ~140 nm to ~1 μm, hence providing an unprecedented view of accretion and ejection tracers at ultraviolet wavelengths. The PENELLOPE program, named in order to underline the complementarity to ULLYSES and to match its spelling flaw, is a public (no proprietary time) community-driven effort. PENELLOPE uniquely provides optical high-resolution (ESPRESSO, UVES, R>60,000) and medium-resolution flux-calibrated optical and infrared spectra (up to 2.5 μm) with X-Shooter (R > 10,000), providing access to information that is otherwise not obtainable with the HST spectra provided by ULLYSES, such as main stellar properties, accurate interstellar extinction, and veiling; kinematics and geometry of the accretion and wind processes, and more.
This data release is focused on the X-Shooter spectra obtained in the PENELLOPE program under Pr.Id. 106.20Z8.002, 106.20Z8.004, 106.20Z8.006, and 106.20Z8.008. The total number of targets included in this data release is 74, of which 6 have been observed in two epochs, and 1 in 3 epochs. In total, this data release comprises 82 X-Shooter spectra, each divided in the three X-Shooter arms (UVB, VIS, NIR), absolutely flux calibrated, corrected for telluric absorption, and with resolution ranging from 5400 to 9700 in the UVB arm, 18400 in the VIS arm, and 11600 in the NIR arm.

## Overview of Observations

This release includes all the X-Shooter spectra of the 74 young stellar objects (survey targets) observed in the PENELLOPE Large Program. We do not include here the 4 ULLYSES monitoring targets BP Tau, GM Aur, TW Hya, and RU Lup, which will be included in a future release together with the high-resolution spectra for the same targets.
The targets of this release are located in 8 star-forming regions, namely Orion OB1, sigma Orionis, Chamaeleon I, Corona Australis, eps Chamaeleon, eta Chamaeleon, Lupus, and Taurus.
The targets of PENELLOPE were selected from the targets of the HST/ULLYSES survey (https://ullyses.stsci.edu/ullyses-targets-ttauri.html), in order to include all the targets initially foreseen for this survey. This list evolved during the course of the survey, and not all targets were observed with the VLT, in particular the targets included in the ULLYSES survey with archival HST data were not observed from the VLT, since the contemporaneity of the observations could not have been achieved.

The observational strategy of the VLT/PENELLOPE program is such that the HST/ULLYSES targets are observed contemporaneously to HST with two major observing modes, that is, high-resolution spectroscopy ($R$ > 70 000) with UVES or ESPRESSO (to be released in a future data release), and medium-resolution ($R$ ~ 10 000–20 000) spectroscopy with X-shooter to obtain broad-wavelength, flux- calibrated spectra (this release). Observations are taken in service mode

with tight absolute time constraints of about three days on the X-shooter observation, and with a time-linked concatenation of observations for the high-resolution data, where the first epochs has a two-day absolute time window, followed by the next with a relative time window of a minimum time separation of one night and a maximum of two nights. The exact intervals of the observations are updated about two weeks before the observations once the HST time windows have been finalized. The observations included in this release were taken between November 27th, 2020 and July 2nd, 2022.

Additional information are available in the paper Manara, Frasca, Venuti et al. 2021, A&A, 650, A196 (https://doi.org/10.1051/0004-6361/202140639).

Future data releases will include the X-Shooter spectra for the 4 monitoring targets mentioned above, and the high-resolution UVES and ESPRESSO spectra obtained for all the PENELLOPE targets.

## Release Content

This data release comprises 82 X-Shooter spectra, each divided in the three X-Shooter arms (UVB, VIS, NIR), thus a total of 246 individual fits files. The spectra are absolutely flux calibrated (in erg/s/cm2/nm), corrected for telluric absorption, and with resolution ranging from 5400 to 9700 in the UVB arm, 18400 in the VIS arm, and 11600 in the NIR arm.
Observing conditions were typically with Image Quality better than 1.2", with a few cases of IQ as high as 1.5" or 2". As described later, flux calibration was achieved using lower resolution wider slits of 5.0", thus the seeing conditions were always good enough to achieve full flux calibration.

The medium-resolution broad-wavelength coverage flux- calibrated spectroscopy is obtained using the X-shooter instrument (Vernet et al. 2011). This long-slit ($11''$) spectrograph provides simultaneous coverage of the region between ~300 nm and ~2500 nm, divided into three arms, UVB ($300 < \lambda < 500$nm), VIS ($500 < \lambda < 1000$nm), and NIR ($1000 < \lambda < 2500$ nm). Each target is observed first using a set of $5.0''$– wide slits in the three arms, leading to a low resolution observation with no slit losses, key to obtain absolute flux calibration of the spectra. Then, using $1.0''/0.4''/0.4''$–wide slits for the UVB, VIS, and NIR arms, respectively, high S/N spectra with $R \sim$ 5400, 18 400, and 11 600 are obtained in the three arms. The exposure times are set such that the S/N at 400 nm is >3–5, resulting in a S/N in the VIS and NIR arms always >100. To mitigate the effects of differential atmospheric dispersion, the slits are always oriented at parallactic angle, apart from known cases where the target is a visual binary with separation $\sim 1''$–$8''$. In those cases the slit is also aligned to include both components of the system.

## Release Notes

The spectra presented in this first data release were reduced with the ESO pipeline available at the time of the reduction. The various steps are described in the paper Manara, Frasca, Venuti et al. 2021, A&A, 650, A196 (https://doi.org/10.1051/0004-6361/202140639). Here we briefly describe the main steps.

### Data Reduction and Calibration

Spectroscopic data reduction was carried out using the ESO Reflex workflow v2.8.5 (Freudling et al. 2013), specifically, the X-shooter pipeline (Modigliani et al. 2010) using the versions corresponding to the time of the observation, between v3.5.0 and v3.6.1. The pipelines carry out the standard steps of flat, bias, and dark correction, wavelength calibration, spectral rectification and extraction of the 1D spectra, and flux calibration using a standard star obtained in the same night.

Additional steps are then performed as follows. The 1D extraction of the X-shooter spectra is carried out with IRAF[5] from the rectified flux-calibrated 2D spectrum in cases where the S/N of the UVB arm is low, and for resolved binaries (see Manara et al. 2021). For the latter cases, particular attention must be paid to the selection of the parameters for apertures definition and trace of the spectrum profile to maximize the signal of the extracted flux, avoiding to mix the spectra of two close stars.

Telluric correction is performed using the *molecfit* (Smette et al. 2015; Kausch et al. 2015) tool v3.0.3 for the VIS and NIR arms of X-shooter. The correction is always performed fitting the atmospheric model directly on the science spectra, since the S/N on the continuum is always high enough to ensure a better correction with respect to using the telluric standard star observed in the same night to compute the model.

Finally, the X-shooter spectra obtained with the narrow slits are scaled to the wide-slit ones to correct for slit losses. This procedure has already been tested in previous works, for example, Mendigutía et al. (2013), Alcalá et al. (2017), Manara et al. (2016a, 2017b), Rugel et al. (2018), and Kóspál et al. (2020), and leads to a typical absolute flux calibration accuracy of 7%.

The released spectra are not corrected for interstellar absorption/reddening.

# Data Format

## Files Types

The X-Shooter spectra contained in this release are in standard Phase 3 FITS format, as described in the ESO Science Data Product Standard version 8 ( http://www.eso.org/sci/observing/phase3/p3sdpstd.pdf ).

Each target and each epoch of observation comprises three FITS files, one for the spectrum of each arm (UVB, VIS, NIR). The naming of the file starts with "*flux_**", to describe that the spectra are flux calibrated, followed by the name of the target, the information on whether the spectrum is telluric corrected ("*_tell_*") and the information on the arm ("*_uvb.fits" or "*_vis.fits" or "*_nir.fits"). If multiple epochs are available, the second (and third) epochs are identified in the filenames as "*ep2*" ("*ep3*").

# Acknowledgements

Based on data obtained in the ESO Very Large Telescope Large Program PENELLOPE (Manara et al. 2021).

This work was funded by the European Union (ERC, WANDA, 101039452). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.
This work benefited from discussions with the ODYSSEUS team (HST AR-16129), \url{https://sites.bu.edu/odysseus/}.
This work was partly funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) in the framework of the YTTHACA Project 469334657 under the project code MA 8447/1-1.

According to the Data Access Policy for ESO data held in the ESO Science Archive Facility, all users are required to acknowledge the source of the data with appropriate citation in their publications.

Since processed data downloaded from the ESO Archive are assigned Digital Object Identifiers (DOIs), the following statement must be included in all publications making use of them:

- *Based on data obtained from the ESO Science Archive Facility with DOI: https://doi.org/10.18727/archive/88*

Publications making use of data which have been assigned an archive request number (of the form XXXXXX) must include the following statement in a footnote or in the acknowledgement:

- *Based on data obtained from the ESO Science Archive Facility under request number <request_number>.*